Quantum optics and information science in multi-dimensional photonics networks

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Classical optical networks have been widely used to explore a broad range of transfer phenomena based on coherent interference of waves, which relate to different disciplines in physics, information science, and even biological systems. At the quantum level, the quantized nature of light, this means the existence of photons and entangled states, gives rise to genuine quantum effects that can appear completely counter-intuitive. Yet, to date, quantum network experiments typically still remain rather limited in terms of the number of photons, reconfigurability and, maybe most importantly, network size and dimensionality.

Photonic quantum systems, which comprise multiple optical modes as well as highly non-classical and sophisticated quantum states of light, have been investigated intensively in various theoretical proposals over the last decades. However, their implementation requires advanced setups of high complexity, which poses a considerable challenge on the experimental side. The successful realization of controlled quantum network structures is key for many applications in quantum optics and quantum information science.

Here we present three differing approaches to overcome current limitations for the experimental implementation of multi-dimensional quantum networks: non-linear integrated quantum optics, pulsed temporal modes and time-multiplexing.

Non-linear integrated quantum devices with multiple channels enable the combinations of different functionalities, such as sources and fast electro-optic modulations, on a single compact monolithic structure.

Pulsed photon temporal modes are defined as field orthogonal superposition states, which span a high dimensional system. They occupy only a single spatial mode and thus they can be efficiently used in single-mode fibre communication networks.

Finally, time-multiplexed quantum walks are a versatile tool for the implementation of a highly flexible simulation platform with dynamic control of the underlying graph structures and propagation properties.